SUBSCRIBER LOOP PLANT OF RURAL TELEPHONE SYSTEMS

A SAMPLING SURVEY

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I. INTRODUCTION

A subscriber loop is defined, for purposes of this paper, as a circuit from a central office to a subscriber's premises. The paper describes the subscriber loop plant of rural telephone systems on the basis of a nationwide sampling survey, early in 1964, of the subscriber circuits of REA telephone borrowers. The object of the survey was to obtain data for use in appraising the quality of the plant, studying procedures for upgrading, and evaluating new product developments, particularly electronic equipment such as carrier systems which provide multiple use of cable pairs. This study and other similar studies are important in REA's efforts to assist borrowers in offering to rural subscribers rates and quality of service comparable with those available to urban subscribers.

The survey covered 1,000 subscriber loops in 781 central office areas of 439 borrowers. Selection of borrowers, central offices, and loops was made on a random basis under a statistical sampling plan devised by the Bell System.[1] The plan was designed to produce a sample that is representative of an overall system or universe, which in this case was 1,375,656 main telephones in approximately 3,900 central office areas of 800 REA borrowers. The survey data included a complete description of the cable and wire plant containing each sampled loop. The data have been computer processed to provide estimates of the important characteristics of the plant. This paper defines the plant components measured in the survey, shows how subscribers are distributed in the average central office area, identifies the most common deviations from present REA design objectives, and presents estimates of the composition and costs of plant in service. The paper also shows that a representative sample was obtained.

II. DEFINITIONS

Fig. 1 is a schematic of a subscriber loop which, for simplicity, is shown with only two working stations. The sketch identifies and defines various loop components that were measured in the survey. In addition to the items in Fig.1, load coil spacings and subscriber end sections of loaded loops were measured. The subscriber end section of a loop is defined as all wire beyond the last load point, including bridge tap.

III. DISTRIBUTION OF SUBSCRIBERS

The survey measurements of airline and route distances to the sampled telephones are summarized graphically in Fig. 2. This graph shows how the subscribers of REA telephone borrowers are distributed in terms of distance from the central office, and also compares REA and Bell System subscriber distributions. The Bell System distribution is based on a 1,000 loop survey made in 1960.[2] The precision of the statistical results is indicated on the graph by a statement as to the width of the 90 percent confidence interval for each estimated mean value. The significance of this computation is discussed in Section VII on "Quality of the Sample."

Fig. 2 shows that, as would be expected, REA borrowers' loops are generally longer than Bell System loops. Compared to the 3.4 mile average for REA loops, Bell System loops average 2.0 miles. More significantly, the graphs show that 20 percent of REA loops but only 2 percent of Bell System loops are longer than 6.1 miles, which is the present limiting length for meeting REA transmission objectives with 24 gauge D-66 loaded cable.

The ratio of route distance to airline distance for REA loops has been computed to be 1.3, which shows that on the average the route is 30 percent longer than the airline distance from central office to subscriber location. This is a statistic that is useful in system engineering and tariff studies.

Fig. 3 shows airline distribution by class of service. The 2-party and 4-party distributions are so nearly alike that they have been combined. For subscribers taking graded (1-, 2-, and 4-party) service, airline distance from the central office averages approximately 3/4 mile, but for 8-party subscribers the average is 4.5 miles.

IV. PLANT DESIGN

Analysis of the survey data has provided information on how well the plant of the borrowers meets present REA design objectives and also has shown what are the most common deviations. Table I summarizes the types of deviations found in the survey and the extent to which each type was found to exist. These are deviations from present transmission objectives. Over the years, REA standards have been raised and, therefore, some of these loops may have conformed to standards in effect at the time the plant was built.

In the analysis in Table I, the survey data were adjusted for loops that contain open wire by counting the open wire portion at one-tenth of its actual length. This adjustment compensates for the difference in capacitance between open wire and exchange type cable.

As Table I shows, the principal deviations are loops having incorrect load spacings, loops longer than 18,000 feet that are not loaded, loops having long bridge taps, long end sections, and only one or two load points. These are items to emphasize in transmission improvement programs.

V PLANT COMPOSITION

There has been an increasing need for information on the composition of loop plant for use in transmission studies and in system engineering studies of new developments such as subscriber carrier systems and line concentrators. To provide

this information, the survey data were inspected at intervals of 1,000 feet. This inspection covered the main route from central office to sampled telephone, excluding bridge taps. At each inspection point, a record was made of the size (number of pairs), gauge, and type of plant containing the sampled circuit.

The results of the composition analysis are shown in Fig. 4. Fig. 4a indicates composition by type of plant. It shows (lower left corner) that underground plant, i.e., cable in conduit, extends less than 1 mile from the central office, with most of it in the first 1,000 feet. Aerial cable predominates to a distance of approximately 3 miles, and beyond that distance open wire is the predominant type of plant. In this cross sectional analysis, the entire 1,000 loops appear only at the central office main frame, i.e., where loop length is zero. At the next inspection point (1,000 feet) the sample has decreased to 909 loops. Thus, as distance from the office increases, the percentages shown apply to a continually diminishing number of loops. This explains the sharp cutoff at 18 miles. At that distance there are only eight sample loops (six in open wire and two in buried plant) and the two buried loops terminate before the next inspection point. On a percentage basis, therefore, buried plant drops abruptly from 25 to 0 percent.

Because this is a sample of borrowers' plant as of early 1964, open wire is much more prominent, and buried plant much less in proportion, than would be the case in a sample of new construction. Buried facilities comprise about 70 percent of the plant now being constructed.

Fig. 4b shows composition in terms of gauge of conductor. At the central office end most of the loops are 24 or 22 gauge, but the amount of 24 gauge tapers off rapidly. The amount of 26 gauge (lower left corner) is extremely small. The gauge pattern shows that 22 gauge is the most common facility in the first 3 miles, and beyond that open wire is the most common type of plant -- steel wire predominating in the 3 to 9.5 mile range and copper covered steel predominating beyond 9.5 miles. Included with the copper covered steel are small amounts of drop wire and copper line wire that were too small to indicate separately.

The gauge pattern in Fig. 4b shows a much higher proportion of 19 gauge and 22 gauge facilities than would be required under present standards. For example, present REA transmission objectives can be met with 24 gauge cable and D66 loading on loops up to 32 kilofeet (6.1 miles), but Fig. 4b reveals no 24 gauge loops as long as this. Similarly, 22 gauge cable can often be used economically on loops up to 9.5 miles by using booster battery and long line adapters where required, but Fig. 4b shows no 22 gauge beyond 8.7 miles. At least a portion of this apparent overgauging is attributable to the fact that most of the sampled plant was designed under earlier standards when the state of the art generally required coarse gauges in order to meet transmission and signalling requirements.

Fig. 4c shows composition in terms of the pair size of the facilities containing the sampled circuits. Most of the circuits leave the central office in cables of 100 or more pairs. However, these relatively large cables usually extend only a short distance. Within 1,000 feet from the office, 50 pair and 25 pair become the predominant sizes and remain so to approximately 1 mile. Beyond a mile there are more 1 to 6-pair facilities than any other size. Further analysis (not covered in Fig. 4c) shows that 200-pair is the most common size at the central office and 1-pair is most common in the 1 to 6-pair range.

VI. LOOP COSTS

Loop costs were estimated on the basis of "standard mile costs" of wires and cables. Standard mile costs are average in-place costs based on recent experience on REA-financed construction projects. They cover the complete installation of cable or wire, including its supporting pole line in the case of aerial plant, and all necessary auxiliary apparatus such as splice cases, load coils, distribution terminals, and so forth. For buried plant, extra lengths are provided for looping through pedestals, and an allowance is made for aerial inserts. Standard mile costs are intended for use in broad systemwide engineering studies. These costs are calculated for all types of outside plant wire and cable configurations.

The procedure was to compute the cost of each sample loop by applying the appropriate standard mile cost to each discrete section of the sample route, then dividing the cost derived for each section by the estimated number of pairs in use in that section, and finally totalling the cost per pair in use for all sections of the route. The resulting loop costs, therefore, are the estimated capital costs of reproducing the existing plant with new plant of basically the same design. Pairs in use were estimated, assuming fills ranging from an average of 70 percent for cable to 100 percent for 1 and 2-pair facilities. These percentages are based on general experience in the industry.

Having developed an estimated cost for each loop, an equation was derived for a cost-versus-length curve that would be the best fit for the array of approximately 1,000 points. Fig. 5 shows the curve for average cost per loop as a function of loop length, and also loop cost per main station. This latter curve was obtained by dividing the cost of each loop by the number of working main stations on that loop and then deriving a cost-versus-length equation as previously. The cost curves are based on 963 loops. Loops longer than 16 miles were omitted because of a scarcity of data beyond that distance, and carrier loops were omitted because our primary interest is to determine broadly what it costs to serve REA borrowers' subscribers using the facilities now in general use. This cost information will provide a base for evaluation of upgrading procedures and for determining the relative economy of new developments, particularly carrier and other electronic apparatus.

The cost-per-loop curve in Fig. 5 shows that the cost increases almost linearly with length at a rate of about $400 per mile for the first 12 miles and at a somewhat greater rate (about $450 per mile) beyond 12 miles. The acceleration in the cost rate beyond 12 miles is the result of an increase in the proportionate amount of 19 gauge, coupled with the fact that in this length range the plant consists mostly of a few circuits of copper covered steel line wire (Fig. 4). Actually, most of the plant at this distance from the central office is a single open wire circuit.

The main station curve in Fig. 5 shows that loop cost per working main station increases at an average rate of about $60 per mile throughout the 16 mile distance.

Although Fig. 5 shows that long loops are very costly, only a small percentage of the loops are in the high cost range. This is shown by Fig. 6, which gives the cumulative percentage distribution of the costs. The median costs are $335 per loop and $125 per main station.

Fig. 7 indicates the amount that structures (pole lines) contribute to the cost of aerial loops. Because buried plant has no such structures, loops containing buried plant were omitted in this analysis. Fig. 7 is based on 702 loops. Actually, the structure costs shown include underground conduit as well as pole lines, but since the amount of conduit is very small, as indicated in Fig. 4a, structure costs may be taken as practically synonymous with pole line costs. The total cost curve in Fig. 7 approximates the cost-per-loop curve in Fig. 5 for the first 10 miles, increasing at a rate of $400 per mile, but beyond 10 miles the cost increases at a greater rate than in Fig. 5 -- about $550 per mile. This is because in the 10 to 16 mile range, pole lines account for a higher percentage of total loop costs. In Fig. 5 this effect was obscured by the buried plant. Fig. 7 indicates that structures generally account for 55 to 60 percent of the total cost of the aerial loops.

Fig. 8 is an analysis of the loop costs that indicates the amount bridge taps contribute to the total cost of loop plant. The average cost of bridge taps ranges from about $170 per loop (50 percent of total loop cost) at 1 mile to nearly $1,300 per loop (20 percent of the total) at 16 miles.

VII. QUALITY OF THE SAMPLE

In any sampling study, a question that naturally arises is: How representative is the sample? We have made several comparisons of the sample (1,000 main telephones) with the universe (1,375,656 main telephones) from which the sample was drawn and there is very good correlation in each case. For example, the percentage distribution of the sample by REA administrative areas is very close to the distribution of total telephones (the universe):

	Sample	Universe
Northeast	16.7%	16.7%
North Central	25.2	25.6
Southeast	21.8	21.4
Southwest	22.2	21.8
West	14.1	14.5
	100.0%	100.0%

Percentage distribution by class of service also is good:

	Sample	Universe
1-Party	23.5%	21.5%
2-Party	10.6	9.8
4-Party	17.2	18.5
8-Party	48.7	50.2
	100.0%	100.0%

Another comparison is given in Fig. 9, which shows a histogram of the sample superimposed on a histogram of the universe, each showing distribution of main telephones by size of exchange. The patterns of the two distributions are very similar. They show that most REA borrowers' exchanges serve 100 to 600 main telephones each and that it is from this range that we have drawn the greatest proportion of sample loops. The next largest grouping in both histograms is in the range 600 to 1,400 main telephones. Most of the differences in the two distributions occur in exchanges serving more than 1,400 main telephones, and these large exchanges account for a relatively small proportion of total telephones. Not shown in Fig. 9 are 8 exchanges serving 3,000 to 8,000 main telephones each. These 8 exchanges contributed 26 of the 1,000 sampled telephones.

The 90 percent confidence intervals given in Figs. 2 and 3 provide another measure of the quality of the sample. For example, the mean route distance is shown (Fig. 2) to be 3.4 miles with 90 percent confidence limits of $\pm$0.2 mile. This indicates that if we should measure the route distance from central office to main telephone for the 1,375,656 main telephones in REA borrowers' plant and compute the mean, the probability is 90 percent that this mean value would fall within the limits 3.4 $\pm$ 0.2 miles.

VIII. CONCLUSIONS

The pattern of subscriber distribution (Fig.2) indicates that half of the subscribers served by REA borrowers are less than 2 miles from the serving central office, 90 percent are within 6 miles, and only 2 percent are more than 10 miles from the office. These are airline distances. Route distances average about 30 percent longer.

The distribution pattern also indicates that under present transmission standards 80 percent of the subscribers (out to 6.1 miles) could be served by 24 gauge cable and, by using booster battery and long line adapters where required, 93 percent of the subscribers (to 9.5 miles) could be served by 22 gauge. However, because most of the sampled plant was designed under earlier standards when coarser gauges were required, the survey data on plant composition (Fig. 4b) reveals much less use of 22 and 24 gauge conductors. We expect to see much more extensive use of 24 gauge in new plant construction. Additional smaller sizes of cable and distribution wire in the finer gauges are being standardized by REA.

The distribution pattern for 8-party subscribers (Fig. 3) is important in considering the field of use for 1-party carrier systems being developed. It shows that only 2 percent of the 8-party subscribers are more than 12 miles, and only 4 percent are more than 10 miles from the central office. Therefore, in order for 1-party carrier systems to serve a large potential market, they must be more economical than physical plant at distances shorter than 10 miles.

The survey data show several ways in which subscriber loops deviate from present REA transmission objectives (Table I). Principal deviations involve incorrect loading system patterns. This information is assisting in the development of transmission improvement programs.

The plant composition analysis reveals (Fig. 4c) that cable size tapers rapidly with distance. Most circuits leave the central office in cables of 100 or more pairs, but beyond a mile from the office 1- to 6-pair facilities are more common than any other size. This explains to some extent why there has been only limited use of concentrators in REA systems. Existing types of concentrators are useful in locations served by 50-pair or larger cable.

The cost of subscriber loops (Fig. 5) averages $400 per mile except for very long loops, but the cost varies over a wide range. Only a small percentage of the loops are in the very high cost

range. The median cost (Fig. 6) is $335 per loop, which amounts to $125 per working main station. These are outside plant costs based on the existing plant facilities, which contain large quantities of open wire and other expensive items. Loop costs for new plant, especially buried facilities, are much lower than those reported here.

Pole lines account for up to 60 percent of the cost of the aerial loops (Fig. 7). This emphasizes the importance of constructing buried plant wherever feasible.

The cost of bridge taps, including supporting pole lines, ranges from 50 percent of the total loop cost of relatively short (1 mile) loops to 20 percent of the total cost of long loops. The high proportionate cost of bridge taps on short loops indicates that significant savings might be achieved in upgrading subscribers close to the central office.

Long bridge taps have an adverse effect on transmission. In designing loop plant, therefore, it is advantageous from both transmission and cost viewpoints to give careful attention to grouping parties on multiparty lines so as to reduce the length of bridge tap to the minimum consistent with required flexibility. The need for bridge taps is expected to be reduced due to the decreasing demand for multiparty service. Also, the general use of plastic cable and ready-access terminals which can be "cut in" as needed will help reduce the need for bridge taps.

Working bridge taps reduce loop cost per main station by spreading the cost of the commonly used portion of the circuit over two or more main stations. Subscriber carrier equipment also has this capability, and it is expected that as low cost solid state equipment becomes available and the demand for 1-party service grows, this equipment will be widely used.

IX. FURTHER WORK

One of the main objectives in conducting the loop survey was to obtain plant data that could be used in studying upgrading procedures and costs. The survey data are being used as a basis for estimating the size and cost of plant additions that would be required to achieve various degrees of upgrading. Estimates are being made for carrier as well as voice frequency transmission systems. Several subscriber carrier systems are under development that are expected to be much less expensive than existing carrier systems in installed cost and also in annual maintenance expense. The loop length at which these systems would break even with physical plant will be determined. Comparison of the break-even points with the subscriber distribution pattern in Fig. 2 will provide an indication of the size of the potential market for new carrier systems.

Another phase of the loop study involves use of the survey data in estimating the voice frequency transmission characteristics of the subscriber loop plant of REA borrowers. Estimates are being made of such transmission characteristics as loop resistance, insertion loss, return loss and input impedance.

X. ACKNOWLEDGMENT

The authors acknowledge invaluable assistance received from Marvin T. Hearst, who had responsibility for the data processing. This involved writing computer programs, arranging for all of the computer processing, and preparation of most of the graphs on an automatic data plotter.

XI. REFERENCES

1. Edwards, H. S., and Hardaway, H. Z., New Concepts in Exchange Outside Plant Engineering, The Bell System Technical Journal, Volume XLIV, Number 3, March 1965, pp. 373-399.

2. Hinderliter, R. G., Transmission Characteristics of Bell System Subscriber Loop Plant, IEEE Transactions on Communication and Electronics, Number 68, September 1963, pp. 464-470.

TABLE I. LOOPS NOT MEETING PRESENT REA TRANSMISSION DESIGN OBJECTIVES FOR LOADING AND BRIDGE TAP	
Deviation	Percent of Loops*
Loops having incorrect load spacings	11.9
Nonloaded loops over 18 000 feet	11.6
Nonloaded loops having bridge tap over 6000 feet	6.3
H-88 loaded loops having end section over 9000 feet . .	7.1
D-66 loaded loops having end section over 12 000 feet .	0.3
Loops having only 1 or 2 load coils	2.3**
Loops having loaded bridge tap	0.6
Loops having bridge tap between load points	0.8

* These percentages should not be totaled because some loops have more than one type of deviation.

** Since 1961, REA has recommended full loading of all loops exceeding 18 000 feet. Prior to this, loading was employed only to the extent needed to meet effective transmission objectives.

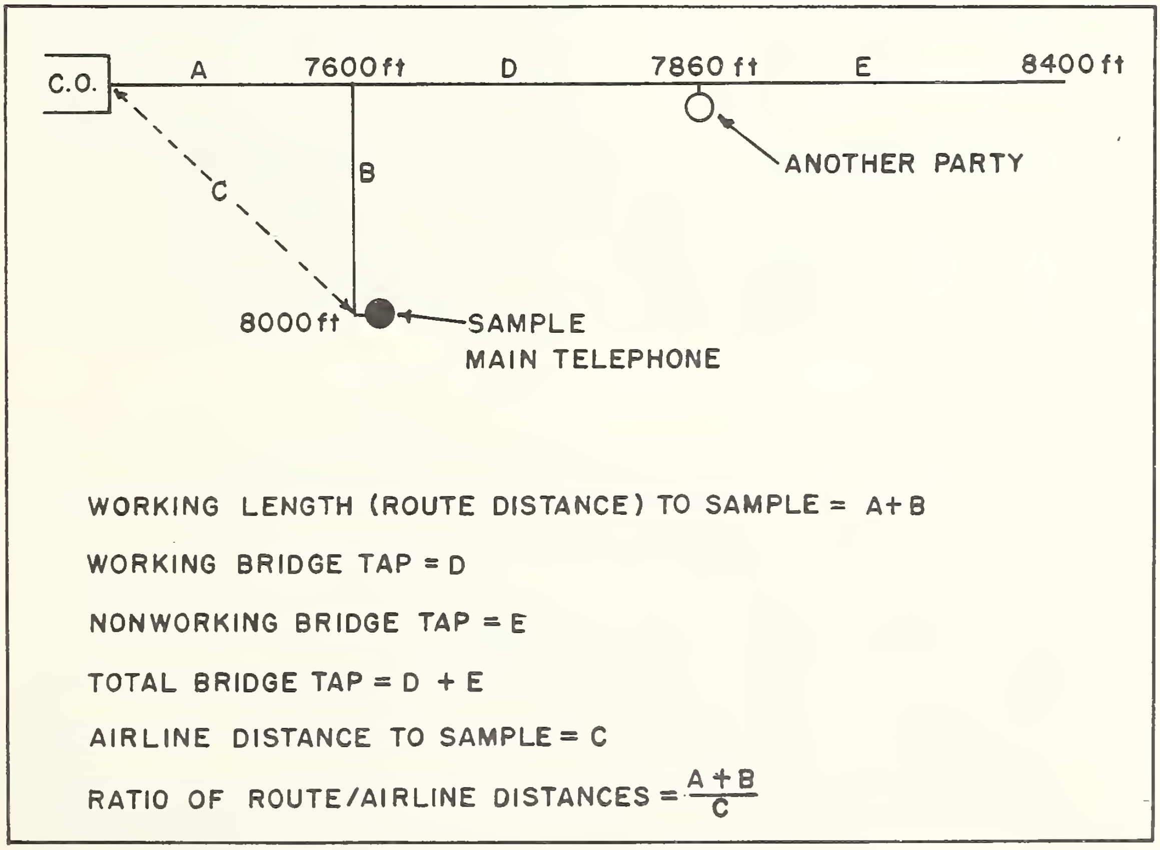

FIG. 1. SIMPLIFIED LOOP SKETCH WITH DEFINITIONS

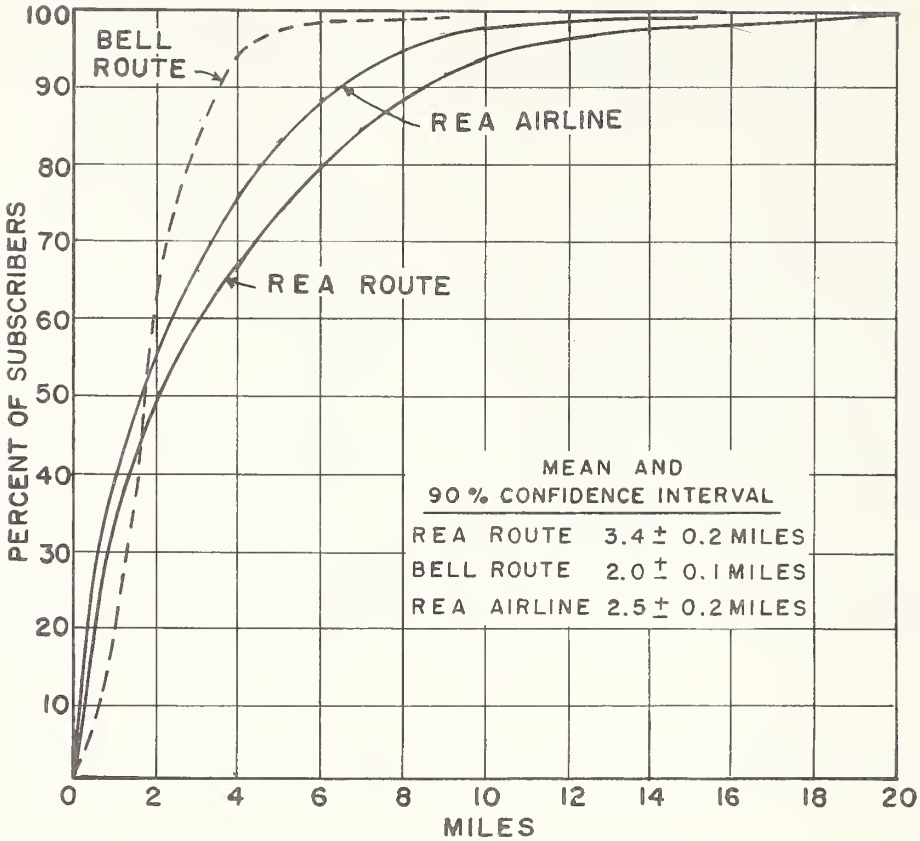

FIG. 2. AIRLINE AND ROUTE DISTANCES - CENTRAL OFFICE TO SAMPLED TELEPHONE

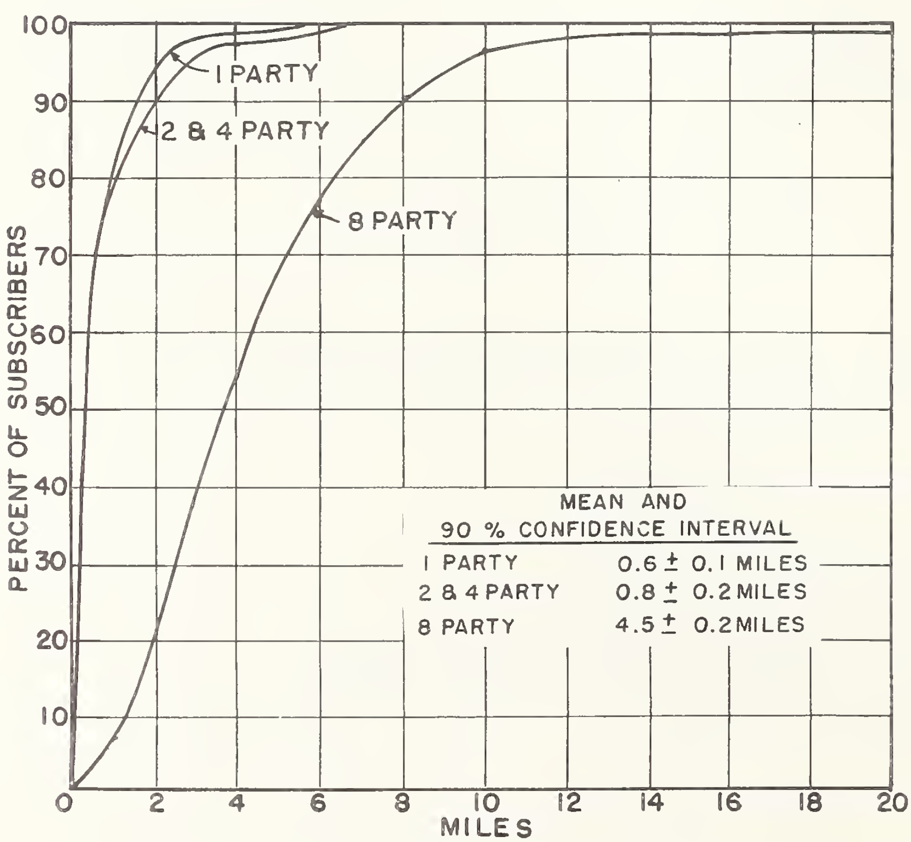

FIG. 3. DISTRIBUTION OF SUBSCRIBERS BY CLASS OF SERVICE
AIRLINE DISTANCE FROM CENTRAL OFFICE

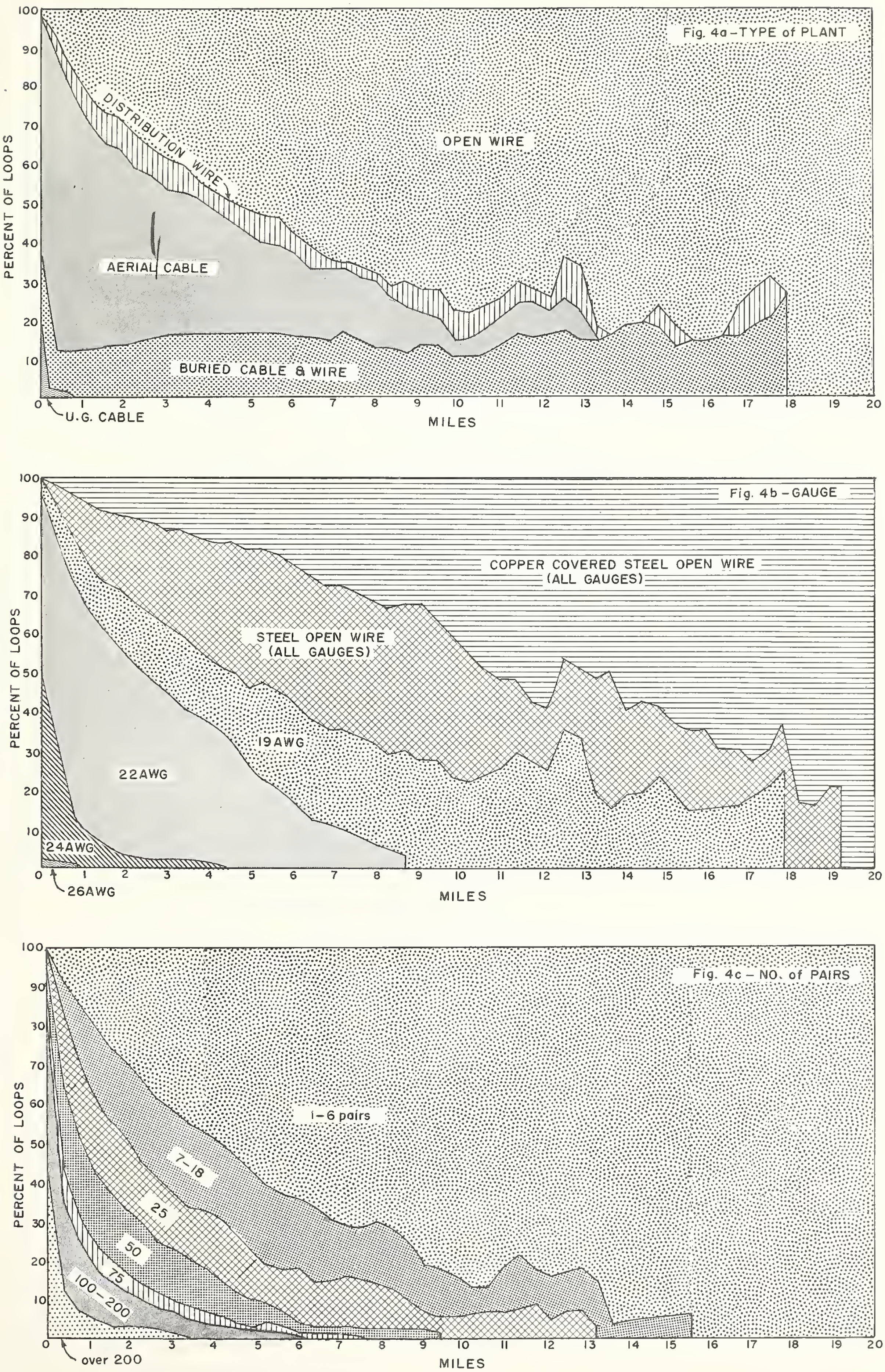

FIG. 4. COMPOSITION OF SUBSCRIBER LOOP PLANT OF REA TELEPHONE BORROWERS

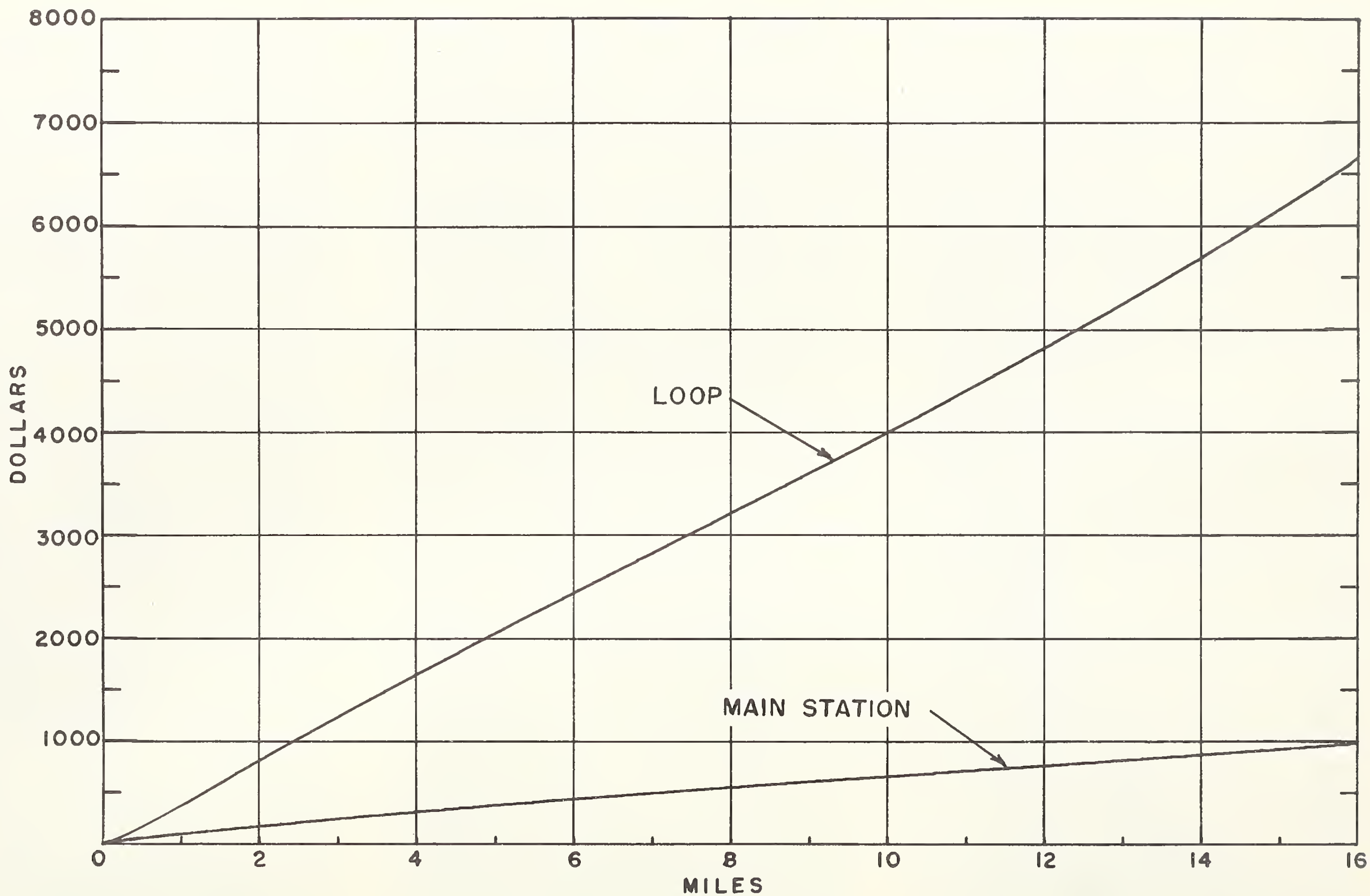

FIG. 5. COST OF SUBSCRIBER OUTSIDE PLANT PER LOOP AND PER MAIN STATION

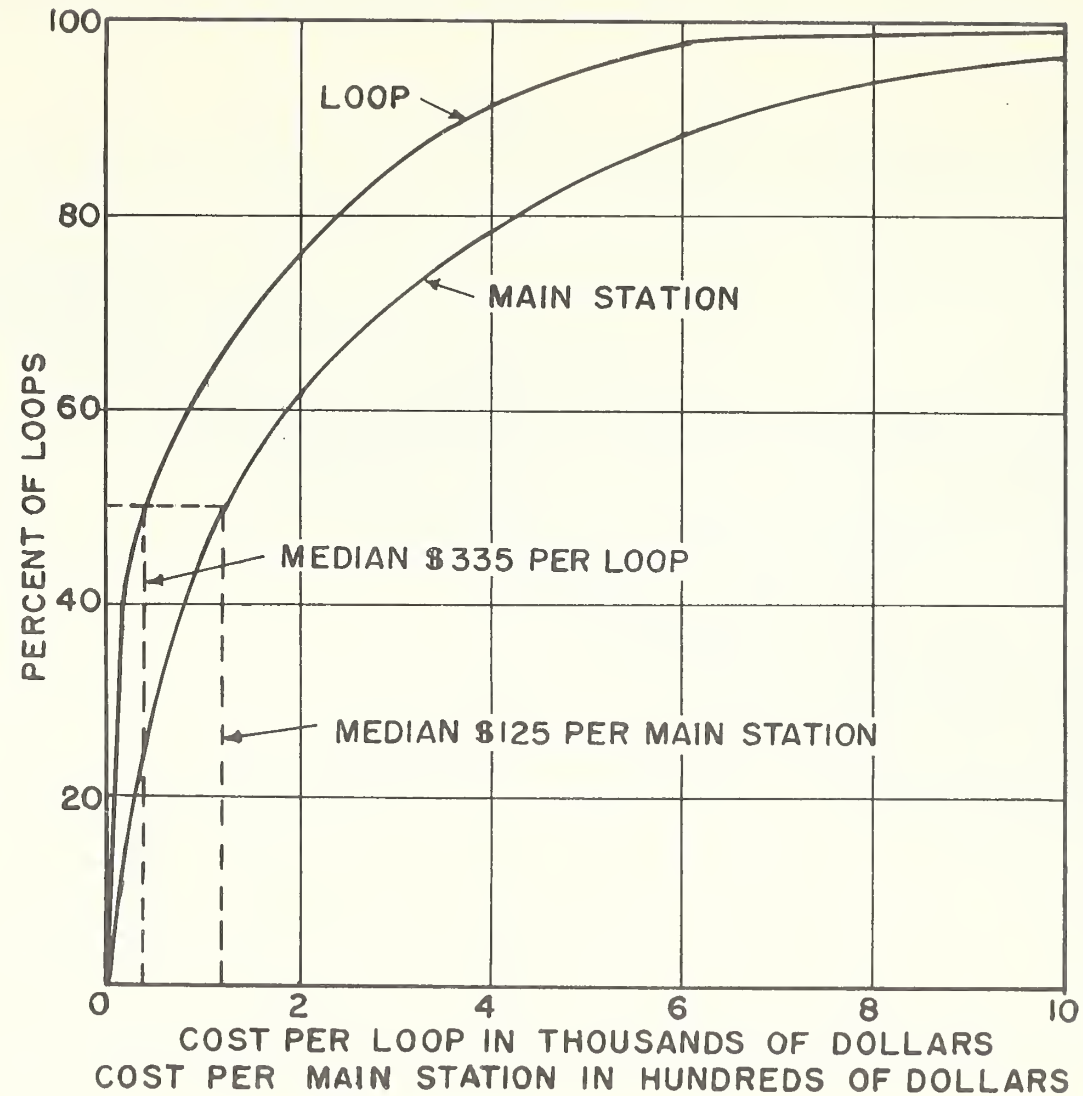

FIG. 6. COST OF SUBSCRIBER OUTSIDE PLANT PER LOOP AND PER MAIN STATION PERCENTAGE DISTRIBUTION

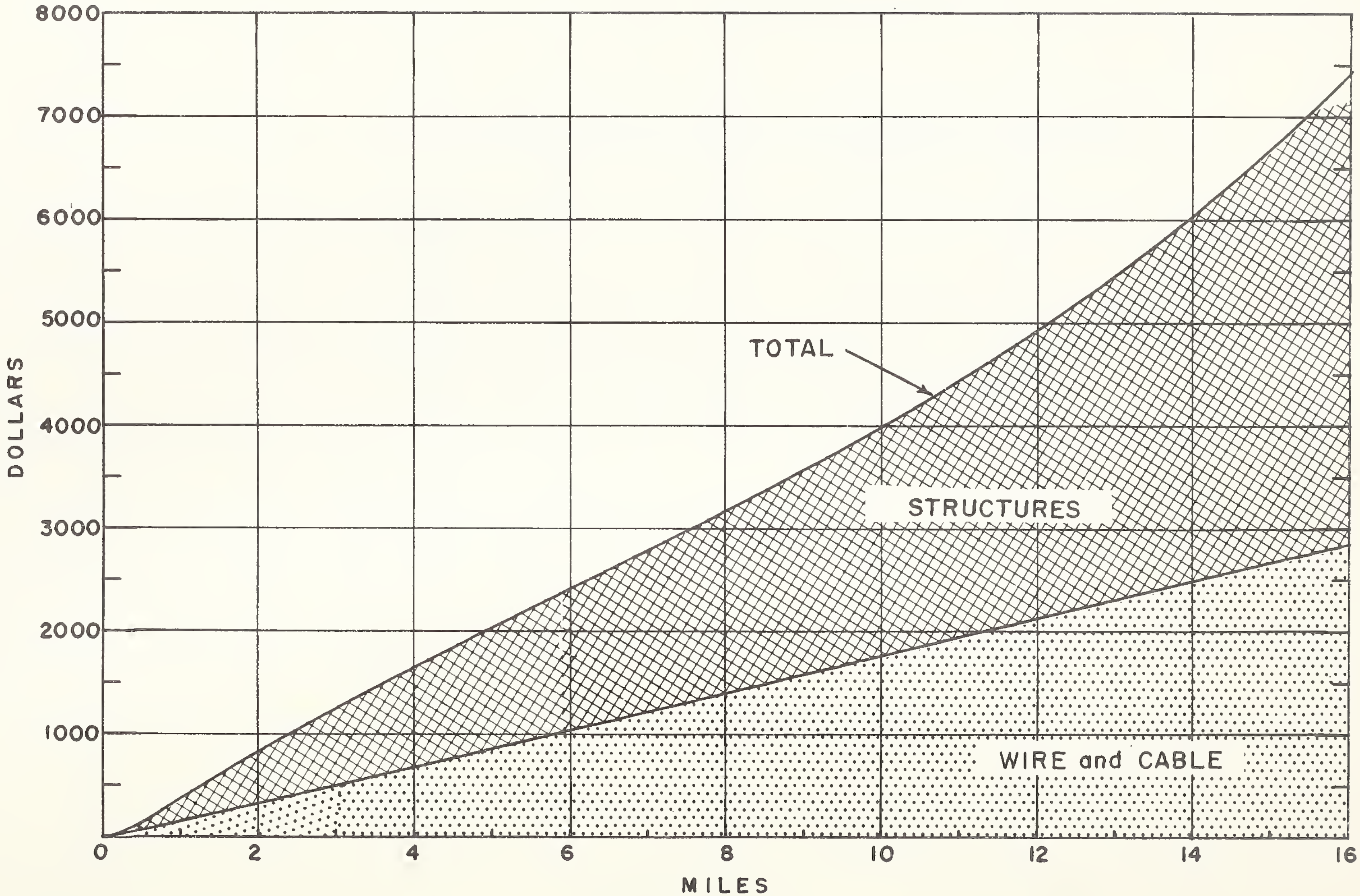

FIG. 7. COST PER LOOP FOR WIRE AND CABLE AND FOR STRUCTURES
(LOOP SAMPLES CONTAINING BURIED PLANT EXCLUDED)

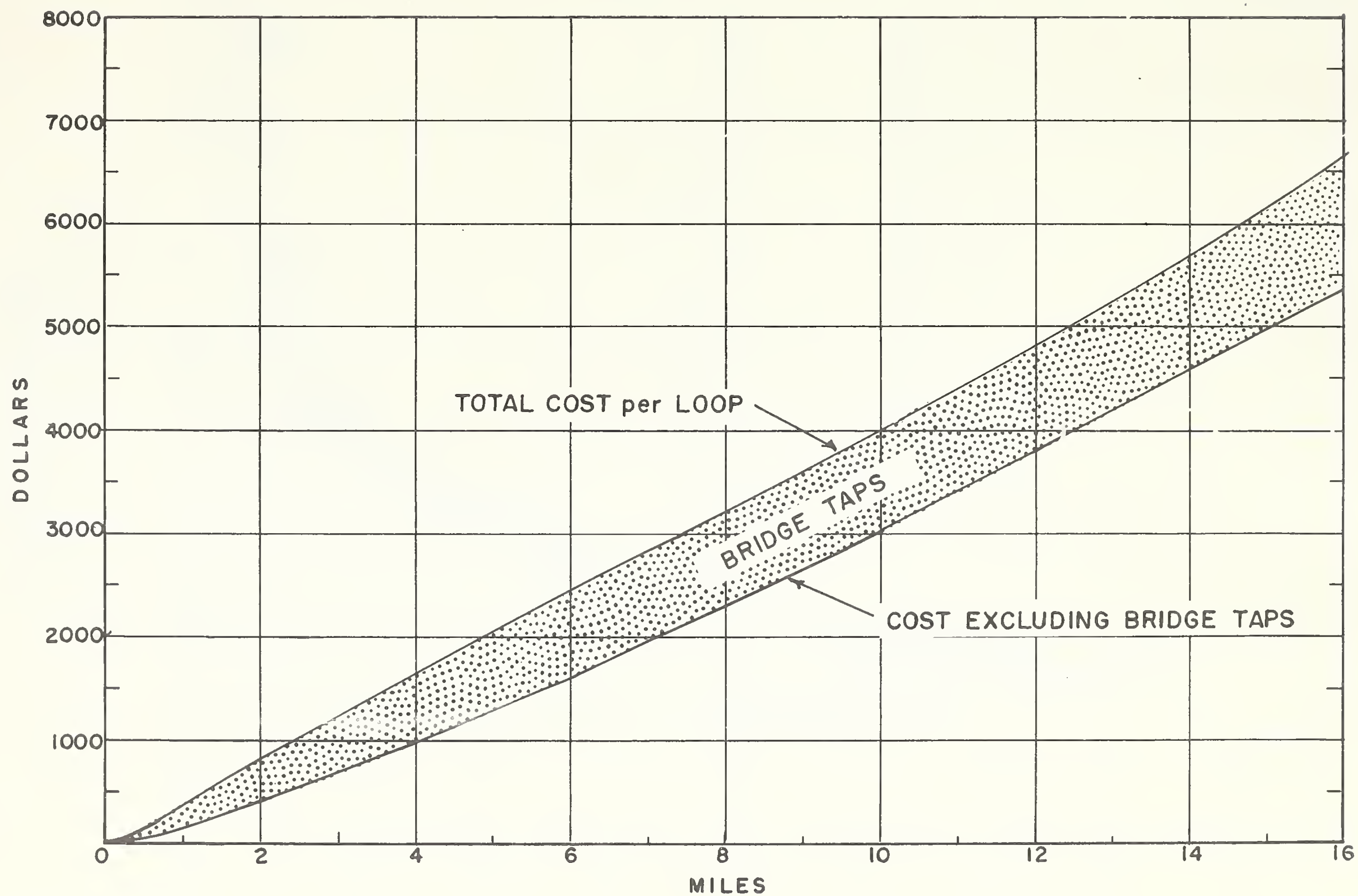

FIG. 8. COST OF BRIDGE TAPS PER LOOP

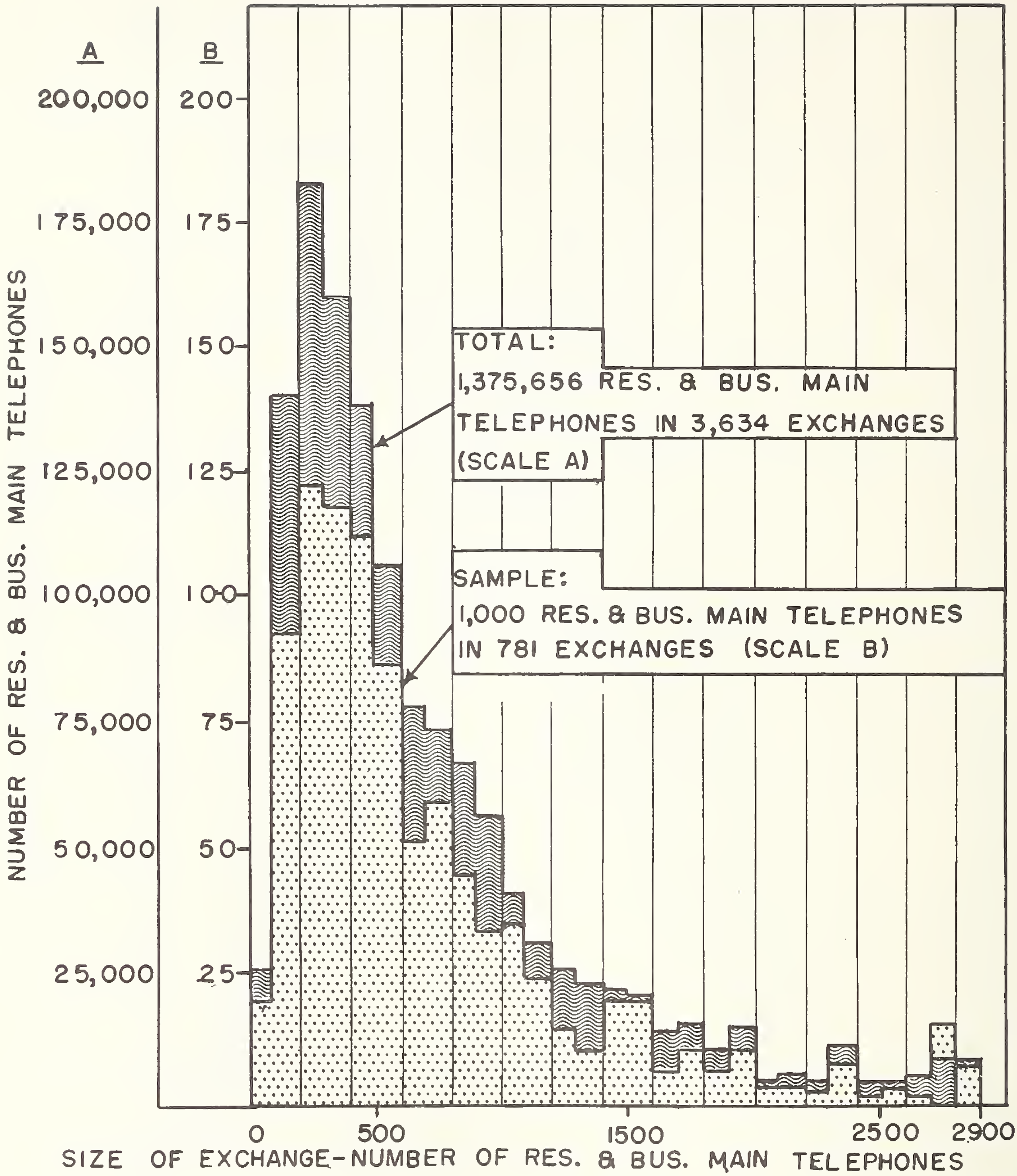

FIG. 9. COMPARISON OF SAMPLED TELEPHONES AND TOTAL TELEPHONES (RESIDENCE AND BUSINESS) BY SIZE OF EXCHANGE